Geologic Resource Evaluation Scoping Summary
Pinnacles National Monument, California

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The Geologic Resource Evaluation (GRE) Program provides each of 270 identified natural area National Park System units with a geologic scoping meeting and summary (this report), a digital geologic map, and a geologic resource evaluation report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and potential monitoring and research needs. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity for discussion of park-specific geologic management issues, and if possible include a site visit with local experts.

The National Park Service held a GRE scoping meeting for Pinnacles National Monument on September 25, 2007. Chief of Resource Management Denise Louie welcomed the participants, and Brant Porter, an interpreter at the national monument, provided a brief history that highlighted many of the monument's scenic and scientific values. Chris Wills (California Geological Survey) presented a general overview of California geology and discussed specific geologic hazards as they pertain to the national monument. Vince Matthews (Colorado Geological Survey) presented information about the geologic history, rock types, and large-scale tectonic movements of Pinnacles National Monument. Tim Connors (Geologic Resources Division) facilitated the assessment of map coverage, and Bruce Heise (Geologic Resources Division) led the discussion of geologic processes and features.

Participants at the meeting included NPS staff from Pinnacles National Monument, Columbia Cascades Office, Geologic Resources Division, Night Skies Program, and Water Resources Division, and cooperators from the California Geological Survey, Colorado Geological Survey, U.S. Geological Survey, and Colorado State University (see table 2, p. 12).

Park and Geologic Setting

Pinnacles National Monument is located between the Salinas and San Benito valleys in the Gabilan Range of California. In 1906 President Theodore Roosevelt proclaimed 5,700 ha (14,080 ac) of San Benito and Monterey counties as Pinnacles National Forest Reserve; this protected the timber, of which there is little, but did not exempt mining claims (Keith 2004). To more fully protect the resources, Theodore Roosevelt proclaimed Pinnacles National Monument on January 16, 1908, which has been considerably expanded since that time. Pinnacles National Monument is named for its topographic features—rocky spires, and crags. Explorer Captain George Vancouver was the first to leave a published record of his visit of the area, which noted the "unusual mountain" (Vancouver 1794). These high relief features are composed of volcanic breccias broken up by numerous joints and cemented with silica from flowing waters. As Brant Porter (Pinnacles National Monument) described during his presentation, the outcome is a "strange" and "striking" landscape. Though rising to heights of only 305 m (1,000 ft), the pinnacles stand out from the surrounding valley.

Porter also said of the landscape that "it didn't belong here." Indeed as Vince Matthews (Colorado Geological Survey) later elucidated, Pinnacles is foreign terrain, making its way from the south near present-day Lancaster, California. Because Pinnacles National Monument contains rocks that are "out of place," it highlights the great movement along the San Andreas Fault. The national monument preserves remnants of an ancient volcano split by the San Andreas Fault. The portion now at Pinnacles National Monument traveled 314 km (195 mi) to the northwest with the Pacific Plate.

Before the plate boundary between the Farallon and North American plates changed from subduction to transform motion, igneous activity formed the volcanic rocks. These rocks are mostly of high-silica, rhyolite composition, but volcanic tuff also originated as ash during eruptions, and lahar deposits were a result of volcaniclastic-rich debris flows. During the transition between converging and transform movement, the Farallon Plate descended below the North American Plate to be replaced by the Pacific Plate. Age dating shows that the volcanic rocks at Pinnacles National Monument formed about 23 million years ago, delimiting the transition from volcanic arc to transform motion in central and southern California. Rocks of similar age and composition in the Mohave Desert, called the Neenach Volcanics, mark the long journey northward; these volcanic rocks lie east of the San Andreas Fault on the North American Plate.

A hike along the Old Pinnacles Trail, which scoping participants took, highlights massive rock with cobblestone-sized, angular blocks called volcanic breccia. These rocks fracture along vertical cracks, resulting in the spectacular pinnacles in the High Peaks area of the national monument. Additionally a combination of fluvial and mass-wasting erosional processes has resulted in the formation of cavities in the jointed rocks: huge boulders have broken off, creating roofs over the cracks and forming talus caves (e.g., Balconies and Bear Gulch). The monument's caves are steeped in legend. Stories that survive are still told around campfires and focus on the notorious central California bandito Tiburcio Vasquez, whose brutal contribution to local history ended with his hanging in San Jose, California, in 1875. Hidden treasure and robber's roosts are part of the local lore, but the location of Tiburcio's cache seems speculative (http://www.nps.gov/pinn/naturescience/naturalfeaturesandecosystems.htm).

Geologic Mapping for Pinnacles National Monument

During the scoping meeting Tim Connors (Geologic Resources Division) showed some of the main features of the GRE Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRE Geology–GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRE Program. Staff members digitize maps or convert digital data to the GRE digital geologic map model using ESRI ArcMap software. Final digital geologic map products include data in geodatabase, shapefile, and coverage format, layer files, FGDC-compliant metadata, and a Windows HelpFile that captures ancillary map data.

When possible, the GRE Program provides large scale (1:24,000) digital geologic map coverage for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands. Maps of this scale (and larger) are useful in resource management because they capture most geologic features of interest and are accurate within 12 m (40 ft). The process of selecting maps for management use begins with the identification of existing geologic maps in the vicinity of the park. Scoping session participants then select appropriate source maps for the digital geologic data to be derived by GRE staff. Table 1 lists the source maps chosen for Pinnacles National Monument.

Pinnacles National Monument has six 7.5-minute quadrangles of interest: San Benito, Bickmore Canyon, Mount Johnson, Topo Valley, North Chalone Peak, and Soledad. As of June 2008, the GRE Program plans to convert digital geologic data from the California Geological Survey to cover the three northern quadrangles: San Benito, Bickmore Canyon, and Mount Johnson. These data are part of the geologic map of the Monterey 30' × 60' quadrangle (scale 1:100,000), though the base scale of the project is 1:24,000.

The GRE Program is in the process of determining how to get data for the three "southern maps"—Soledad, North Chalone Peak, and Topo Valley. The Dibblee Geological Foundation—a non-profit organization created to preserve the scientific, technical, educational, and economic values of Tom Dibblee's life work through timely publication (http://www.sbnature.org/dibblee/newweb/about.html)—has published (and copyrighted) each of these quadrangles, so GRE staff needs to discuss with this foundation whether these geologic data could be available for GRE use.

Additionally, Vince Matthews has produced a geologic map of part of the area; this map significantly subdivides the igneous rocks. Staff at the national monument would like Vince Matthews' map of volcanic units in a digital GIS format; GRE staff will digitize this map. Monument staff also mentioned that they have maps of park caves, floodplains, wells, springs, mines, rock-climbing areas, and landslide maps. GRE staff would like to obtain this information from staff at Pinnacles National Monument or the San Francisco Bay Area Network and incorporate into the final GRE product.

Table 1. Source Maps for Pinnacles National Monument

GMAP ID	Reference	GRE appraisal
63595	Wagner, D. L., H. G. Greene, G. J. Saucedo, and C. L. Pridmore. 2002. *Geologic map of the Monterey 30′ × 60′ quadrangle and adjacent areas, California*. Scale 1:100,000. Regional Geologic Map Map 1. Sacramento, CA: California Geological Survey.	2008-0404: have both published paper and CD-ROM copies from CAGS; covers multiple PINN QOIs and should be used for the San Benito, Bickmore Canyon, and Mt. Johnson 7.5′ quads
74484	Matthews, V. 2004. Geologic map of Pinnacles Volcanic Formation, California. Scale 1:24,000. Unpublished data.	2008-0404: Tim received printed copy from Vince Matthews; has no lat-long info on it. Need digital GIS files and full citation from Vince.
74918	Dibblee, T. W., and J. A. Minch. 2006. *Geologic map of the Soledad quadrangle, Monterey County, California*. Scale 1:24,000. Map DF-245. Camarillo, CA: Dibblee Geological Foundation.	2008-0404: PINN non-intersecting QOI, but likely have digitally already in GMAP 63595 (Monterey 30' × 60')
74813	Dibblee, T. W., and J. A. Minch. 2007. *Geologic map of the North Chalone Peak quadrangle, Monterey and San Benito counties, California*. Scale 1:24,000. Map DF-303. Camarillo, CA: Dibblee Geological Foundation.	2008-0404: PINN intersecting QOI; GRE has paper copy from Dibblee Foundation map but needs to resolve copyright issues before being able to use; not known to be digital GIS-based
74810	Dibblee, T. W., and J. A. Minch. 2007. *Geologic map of the Bickmore Canyon quadrangle, Monterey and San Benito counties, California*. Scale 1:24,000. Map DF-320. Camarillo, CA: Dibblee Geological Foundation.	2008-0404: PINN intersecting QOI; GRE has paper copy from Dibblee Foundation map but needs to resolve copyright issues before being able to use; not known to be digital GIS-based
74812	Dibblee, T. W., and J. A. Minch. 2007. *Geologic map of the Topo Valley quadrangle, Monterey and San Benito counties, California*. Scale 1:24,000. Map DF-304. Camarillo, CA: Dibblee Geological Foundation.	2008-0404: PINN intersecting QOI; GRE has paper copy from Dibblee Foundation map but needs to resolve copyright issues before being able to use; not known to be digital GIS-based
74811	Dibblee, T. W., and J. A. Minch. 2006. *Geologic map of the Gonzales and Mount Johnson quadrangles, Monterey and San Benito counties, California*. Scale 1:24,000. Map DF-234. Camarillo, CA: Dibblee Geological Foundation.	2008-0404: PINN non-intersecting QOI; GRE needs paper copy from Dibblee Foundation map but needs to resolve copyright issues before being able to use; not known to be digital GIS-based
74809	Dibblee, T. W., and J. A. Minch. 2007. *Geologic map of the San Benito quadrangle, San Benito County, California*. Scale 1:24,000. Map DF-234. Camarillo, CA: Dibblee Geological Foundation.	2008-0404: PINN intersecting QOI; GRE has paper copy from Dibblee Foundation map but needs to resolve copyright issues before being able to use; not known to be digital GIS-based

Notes: QOI = quadrangle of interest
GMAP numbers are identification codes for the GRE Program's database

Geologic Features, Processes, and Resource Management Issues

The scoping meeting at Pinnacles National Monument provided an opportunity to develop a list of geologic features, processes, and related resource management issues, which will be further explained in the final GRE report. Though not discussed during scoping, the geomorphology of pinnacles will be described in the final report. During scoping, participants did not prioritize the issues, but discussion made it clear that seismicity and caves have high management significance. These are discussed first, followed alphabetically by other features and processes at the national monument.

Seismicity

Pinnacles National Monument is adjacent to the "creeping" section of the San Andreas Fault. This creeping segments starts at San Juan Batista and goes south to Parkfield; it moves at a rate of about 30 mm (1.2 in) per year, which is the maximum creep anywhere along the San Andreas Fault. Major or severe earthquakes have a lower probability of occurring here than along "slipping" sections of the fault. Shaking hazards are lower here than along other segments of the fault. Because a gap in movement takes up most of the strain, vigorous quakes generally do not rupture in the creeping section. However shaking is still significant enough to initiate rockfall. Moderately intense ground shaking is likely in the near future whether it originates from faults nearby or locked-fault segments farther north and south (http://www.nps.gov/pinn/naturescience/naturalfeaturesandecosystems.htm).

As GRE staff observed during a quick tour of the nearby town of Hollister, several sidewalks have been torn by fault creep. Expressions of seismic activity also abound at Pinnacles National Monument: streams show characteristic offsets as they cross faults, and valley bottoms and terraces are evidence of localized uplift. These and other features will be discussed in the final GRE report.

Since the Pinnacles Volcanics were transported to this area, the San Andreas Fault has moved 8 km (5 mi) to the east. The original location of the San Andreas is the current location of the Chalone Creek Fault. A large chunk of sandstone jammed the San Andreas and caused it to move to the east (Matthews and Webb 1982).

Small to moderate earthquakes are frequently felt within the monument. Visitors and staff commonly feel magnitude-2 (on the Richter scale) quakes, which they also hear as distant sonic booms. The U.S. Geological Survey monitors seismic activity in the monument using a seismometer along the Chalone Creek Fault and a corresponding seismograph in the Bear Gulch Visitor Center. Investigators from University of California–Berkeley conducted an extremely accurate survey of seismicity (primarily strain) in the national monument, taking measurements on Chalone Peak. The seismograph in the visitor center provides a continuous record of seismic activity; visitors are able to see the seismograph and confirm their suspicions of previously felt ground movement (http://www.nps.gov/pinn/naturescience/naturalfeaturesandecosystems.htm). Park staff would like to have the location of earthquakes as part of their GIS. The U.S. Geological Survey has these data available at http://earthquake.usgs.gov/eqcenter/.

Caves

Pinnacles National Monument has two main areas of caves: the Bear Gulch Caves, near headquarters, and the Balconies Caves, near the Chaparral Campground. The two largest caves are about 180 m (600 ft) and 460 m (1,500 ft) in length. In addition, a few poorly documented areas of small talus caves are scattered throughout the monument (http://www.nps.gov/pinn/naturescience/naturalfeaturesandecosystems.htm). The caves formed by stream erosion along vertical joints associated with strands of the San Andreas Fault and by toppling of "cyclopean boulders" during large earthquakes (Hinds 1952, Rogers 2003, Rogers et al. 2003). Going into the caves is a primary visitor attraction, and park managers are concerned about rockfall hazards. After each magnitude 4 or greater earthquake, park staff examines the caves to identify high-risk areas. Safety hazards are also associated with flooding, as many of the caves have formed in narrow gorges.

Caves in the national monument serve as sensitive habitat for bats (e.g., Townsend big-eared bat [*Corynorhinus townsendii*]) during both summer and winter. Park managers have installed bat-friendly gates to allow bat but not human entry; thereby bats can move throughout the caves to select habitat, which park managers monitor. Speleothems typical of karstic environments do not form in the monument's caves; however, scoping participants mentioned the occurrence of opalite crystals. Rogers (2003) identified some other interesting mineralogy: clear to milky white cristobalite coralloids; biogenic cristobalite diatom moonmilk; powdery white crusts and yellow moonmilk of gypsum; seasonal ice speleothems; thin, blue-black biogenic deposits of birnessite; and dull to lustrous brown-colored deposits of amberat.

In the 1930s, the Civilian Conservation Corps built trails through the caves; these trails have endured many storms and travelers. Constructed stairways and bridges were needed to navigate the caves without the use of ropes and ladders (http://www.nps.gov/pinn/naturescience/naturalfeaturesandecosystems.htm).

Climatic Change

"A climate disrupted by human activities poses such sweeping threats to the scenery, natural and cultural resources, and wildlife of the West's national parks that it dwarfs all previous risks to these American treasures," so states *Losing Ground: Western National Parks Endangered by Climate Disruption* (Saunders et al. 2006). The authors contend that "a disrupted climate is the single greatest threat to ever face western national parks." Because of the potential disruption that climate change could cause to park resources, including geologic features and processes, the GRE Program has begun to include a discussion during scoping meetings of the effects of climate change to park resources. Participants at the scoping meeting identified the following as possible outcomes of climate change at Pinnacles National Monument: (1) oscillation of severe weather events and the subsequent impacts on the magnitude of flooding and number of debris flows, (2) impacts on flora and the associated repercussions for debris flows and flooding, and (3) latitudinal shifts in weather patterns to the north or south impacting vegetation (e.g., valley oaks).

Rainfall records dating back to 1936 indicate that the area between San Francisco and Hollister, including the Pinnacles area, may experience the greatest changes along the Pacific Coast as a result of climate change. Though the record shows that the overall "rainy season" has shortened, the overall trend is toward a slight increase in precipitation over the last 70 years. Shoulder seasons, particularly May, show a sharp warming trend. Park mangers have obtained a 500-year, tree-ring record from blue oaks, which grow on well-drained soil in the monument; this dataset may provide a high resolution record of El Niño events.

Disturbed Lands

Modern human activities have disturbed more than 127,480 ha (315,000 ac) in 195 National Park System units. Some of these features may be of historical significance, but most are not in keeping with the mandates of the National Park Service. Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by mining activities, development (e.g., facilities, roads, dams, abandoned campgrounds, and user trails), agricultural practices (e.g., farming, grazing, timber harvest, and abandoned irrigation ditches), overuse, or inappropriate use. Usually lands disturbed by natural phenomena such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires are not considered for restoration unless influenced by human activities.

Restoration activities return the quality and quantity of an area, watershed, or landscape to some previous condition, often some desirable historic baseline. To accelerate site recovery, restoration at disturbed areas directly treats the disturbance and aims to permanently resolve the disturbance and its effects. For more information about disturbed lands restoration, contact Dave Steensen (Geologic Resources Division) at dave_steensen@nps.gov or 303-969-2014.

Because the rocks at Pinnacles National Monument appear "so unusual," many people over the years have thought "there must be minerals here." Indeed, Pinnacles National Monument contains the remains of past mining operations such as adits and, though partially restored between 2001 and 2004, a quarry for perlite. Scooping participants also noted a 155-m (510-ft) adit, presumably dug by the Civilian Conservation Corps (CCC) in the 1930s "for fun" in an attempt to find gold. However, since scoping Landscape Historian Timothy Babalis (Pacific West Regional Office) clarified that this "gold mine" has no connection to the CCC. Rather it is the Chalone Claim on Mt. Defiance, the only gold mine on the monument. Thomas Flint and partners dug the adit in 1892 but gold never assayed rich enough to be profitable (ores contained only 0.03 oz. gold per ton), and they abandoned the venture the same year. The site is just southwest of the summit of Mt. Defiance in the southeast quarter of Section 11, Township 17 South, Range 7 East (SE ¼ of Sec. 11, T17S, R7E) and overlooks Frog Canyon. Notably this mine is now an active bat site (Timothy Babalis, Pacific West Regional Office, e-mail communication, January 31, 2008).

A copper mine, now abandoned, occurs on the west side of the monument, in the SW ¼ of Sec. 33, T16S, R7E. Henry Melville of the Copper Mountain Mining Company dug several shafts and open cuts at the site between 1872 and 1924. Timothy Babalis believes that the National Park Service filled in the shafts, but the tailings are still visible on the hillside just above the overflow parking lot west of the Chaparral Ranger Station (Timothy Babalis, Pacific West Regional Office, e-mail communication, January 31, 2008).

In 1955, two prospectors, Bobby Davis and Joe Minton, located a uranium claim in Crowley Canyon at the foot of the northeast face of the Balconies. A 30-m- (100-ft-) deep tunnel remains. A geologist from the Atomic Energy Commission reported that they had found autunite, a low-grade uranium ore. The mine was abandoned the same year. This mine is in the SW ¼ of Sec. 27, T16S, R7E (Timothy Babalis, Pacific West Regional Office, e-mail communication, January 31, 2008).

In 1951, a wildcat well was drilled to a depth of 987 m (3,239 ft) but produced no oil. The location is slightly northeast of the head of McCabe Canyon in Sec. 14, T16S, R7E. In general, the fanglomerates east of the Chalone Fault are thought to be capable of possessing oil. The Bitterwater District 11 km (7 mi) away has produced oil (Timothy Babalis, Pacific West Regional Office, e-mail communication, January 31, 2008).

Current mining includes a gravel pit downstream of the national monument near Solidad. This operation affects the migration of the threatened steelhead trout (*Oncorhynchus mykiss*).

Acquisition of new land as part of Pinnacles National Monument resulted in the National Park Service becoming the stewards of lands with grazing; however, this practice was discontinued in 2006. Though park mangers have built a new fence around the perimeter of the monument to keep livestock out, trespass still occurs. Trespass and brushing (with fire) along the fence line may be causing increased erosion. In addition fire roads, dirt roads, and bulldozer lines from fire suppression may enhance erosion and sedimentation.

Fluvial Features and Processes

During scoping, participants estimated that 32 km (20 mi) of streams run through Pinnacles National Monument. Most development is in riparian areas because before the most recent land acquisition, the only “flat lands” were in floodplains or on debris-flow cones (see “Hillslope Features and Processes” section). Poorly sited development has resulted in repeated flood damage over the years, on approximately 20-year cycles. Creeks quickly rise with 10–12 cm (4–5 in) of continuous precipitation. Flooding, which occurs during winter frontal storms (November–April), is “flashy” with heavy runoff. The entire bed of the channel moves during these events, with large boulders of 1.8 metric tons (2 U.S. tons) and 1.5 m (5 ft) in diameter being transported. In cooperation with the National Park Service, the U.S. Geological Survey studied flood-hazard potentials within the boundaries of the national monument (Meyer 1995). Park staff needs to consider hazards during the appropriate placement of any future infrastructure (e.g., buildings, roads, culverts, and campgrounds) on the newly acquired lands.

Many creek beds at the national monument are lined with porous alluvium. During a storm, a creek may become a roaring cascade, but this is short lived. Water quickly percolates beneath the surface after the rain ceases (Ewing 1996). According to Keith (2004), moisture is always close to the surface—no more than 0.6 m (2 ft) below the top of a streambed. Perpetual underground waters drip even during the summer.

Park managers are in the process of restoring Chalone Creek by removing the Old Pinnacles Road from the corridor. The Old Pinnacles Road is a dilapidated 3-km- (2-mi-) long raised gravel road that wanders back and forth through the floodplain and riparian corridor. Used by vehicles until 1974, it is now only passable by foot. This raised structure severely alters the natural fluvial process by confining overbank flow. The result is increased channel bank erosion, incision, and sediment load. Much of this section of stream is existing or potential habitat for the federally threatened California red-legged frog (*Rana aurora draytonii*). The negative effects of the road propagate at least 3 km (2 mi) downstream. Park managers plan to remove 1.2 km (0.75

mi) of this road to allow the creek unobstructed access to its floodplain. Other mitigation measures include rerouting the foot trail to lessen the impact upon the riparian corridor, restoring targeted areas of the channel bank using bioengineering techniques, filling and re-contouring abandoned rock and aggregate quarries, and revegetating the entire area (Moore and Leatherman 2005).

Hillslope Features and Processes

Landsliding has always been part of the Pinnacles' landscape. For instance, Vince Matthews (Colorado Geological Survey) mentioned lahars as depositing agglomerate during Miocene volcanism (23 million years ago). More recent debris-flow deposits lop across the landscape, notably along the Chalone Creek Fault. The California Geological Survey has produced maps of the area that depict numerous landslides. The sedimentary rocks to the east of the national monument and volcanic rock (e.g., agglomerate) within the monument supply landslide material. A significant source of mass-wasting material in the monument is talus (see "Caves" section).

Park managers are in the process of preparing the monument's general management plan. Planning will include recommendations for getting infrastructure away from slide areas.

Lacustrine Features and Processes

Though newly acquired park lands host stock ponds and a small ephemeral basin, Bear Gulch Reservoir is the only sizeable lake in Pinnacles National Monument. Western spadefoot toad (*Spea hammondii*) and the endangered California tiger salamander (*Ambystoma californiense*) inhabit the ponds, as well as as exotic predators such as green sunfish (*Lepomis cyanellus*) and bullfrogs (*Rana catesbeiana*). Relict pools that fill during rainfall are scattered throughout the monument; these may be fault-related sag ponds.

Built by the National Park Service as a human water supply (primarily for fire suppression), the reservoir now provides habitat for the California red-legged frog. Native to the area, park managers introduced this threatened species to the reservoir as part of a reestablishment project. Sediment is filling the reservoir, and park managers are considering options for preserving this habitat.

Paleontological Resources

Will Elder (Golden Gate National Recreation Area) conducted a preliminary inventory of the paleontological resources in the San Francisco Bay Area Network (see Elder et al. 2007). Volcanic and metamorphic rocks—which only rarely contain fossils (e.g., ash-fall deposits at Florissant National Monument in Colorado and tree molds at Craters of the Moon National Monument in Idaho)—dominate Pinnacles National Monument; therefore, the occurrence of paleontological resources may seem unlikely. However, fossils make an unusual appearance because a portion of the Pinnacles Volcanics was deposited in a marine environment; poorly preserved micromarine fossils (Matthews and Webb 1982), possibly ostracodes (3 mm [0.12 in]) and other fossil-like remains (i.e., foraminifera), occur here. During scoping Vince Matthews (Colorado Geological Survey) highlighted these fossils in his presentation with notable sites along the Condor Gulch Trail. Graded bedding and rip-up and flame structures suggest underwater deposition of the tuff, some of which may have been in freshwater environments. Some clasts in the dacite breccia of the Pinnacles Volcanics resemble fossil wood and may be woody material (Phil Stoffer, U.S. Geological Survey, personal communication to Will Elder, September 2007).

The Miocene and Pliocene (23–1.8 million years ago) formations surrounding the park are fossiliferous, and stream beds in the area are known to yield fossils (Phil Stoffer, U.S. Geological Survey, personal communication to Will Elder, September 2007). Terrace deposits often yield paleontological resources such as large Pleistocene (1.8 million–11,000 years ago) mammals (e.g., *Equus*), but no such finds have yet been reported from the national monument. The likelihood of recent deposits of sand and gravel along Chalone Creek and its tributaries containing in situ fossils is low (Andrews 1936); however, if Chalone Creek cuts through fossiliferous layers, fossils may be found in the alluvial deposits of the creek similar to those discovered in stream banks near (but outside) the national monument (Phil Stoffer, U.S. Geological Survey, personal communication to Will Elder, September 2007).

Possibly future research will uncover fossils within the sedimentary rocks of the Monterey Formation. According to Elder et al. (2007), immediately adjacent to the monument's eastern boundary in Bear Valley, the Temblor Formation is conformably overlain by white, chalky, diatomaceous shales and interbedded sandstone considered to be part of the Monterey shales that Kerr and Shenck (1925) described. The shale is rich in diatom (*Coscinodiscus incretus*) and bivalve (*Arca* sp.) fragments; an echinoid and fish bones and scales also occur (Kerr and Shenck 1925). Given their exposure immediately adjacent to Pinnacles National Monument, field investigations may yield the discovery of these fossils within the monument's boundaries.

No one has yet described any paleontological resources from the caves in the national monument. However, Rogers et al. (2003) notes the presence of bats, so depending on how long these animals have inhabited the caves, bat fossils may be present (Elder et al. 2007). Rogers (2003) also notes the occurrence of packrat (*Neotoma*) droppings in the cave. Packrat middens are important paleontological resources as they record local paleoecological conditions (Elder et al. 2007). Middens are known from many caves throughout the National Park System (Santucci et al. 2001), but none are yet documented within Pinnacles National Monument (Elder et al. 2007).

Periglacial Features and Processes

Pinnacles National Monument has excellent examples of needle ice. Also known as "pipkrate," Neuendorf et al. (2005) defines this feature as "a small, thin spike or needlelike crystal of ground ice, from 2.5 to 6 cm in length, formed just below, and growing perpendicular to, the surface of the soil in a region where daily temperatures fluctuate across the freezing point. It is common in periglacial areas, where it contributes to the sorting of material in patterned ground and to downslope movement of surface material." Scoping participants estimated the crystals at the national monument to reach 5 cm (2 in) or more in height. They also suspected that vegetative cover influences needle ice.

In 1999 Vince Matthews prepared a paper about the needle ice in Big South Fork River and National Recreation Area on the border of Tennessee and Kentucky. He concluded that three key factors appear to have contributed to the formation of needle ice: (1) initially warm ground temperature allowing high water penetration into the soil during heavy precipitation; (2) existence of dried stalks that served as conduits to draw the moisture out of the ground; and (3) an extremely low air temperature occurring over warmer, moist ground (Matthews 1999). Though further scientific study is required, these factors may be applicable to the needle ice forming at Pinnacles National Monument.

Volcanic Features and Processes

No active volcanism is occurring at Pinnacles National Monument. Nevertheless calling Pinnacles a "volcanic park" seems appropriate based on its geologic past. Perhaps the most significant volcanic feature is the correlation of the Pinnacles and Neenach volcanic formations; this correlation has become a "classic example" of plate tectonics for the scientific community. As highlighted in the "Park and Geologic Setting" section of this scoping summary, these two rock formations were once part of the same volcano; they lie respectively west and east of the San Andreas Fault zone and are now separated by 314 km (195 mi). Ten rock types with nearly identical field, petrographic, and chemical characteristics are present in each formation in essentially the same stratigraphic order (Matthews 1976). This provides ample evidence for the correlation and interpreted movement along the San Andreas Fault.

The various rock types are also distinctive volcanic features at the national monument: vitric lapilli tuff, flow-banded rhyolite, perlite, pumice lapilli tuff, hypocrystalline hypersthene andesite, augite-olivine andesite,

andesite tuff, porphyritic dacite, agglomerate, and porphyritic rhyolite (Matthews 1976). Additionally, though an igneous-intrusive rather than volcanic feature, andesite has formed sills and dikes in the bedrock. The preceding two sentences are notably jargon rich; nevertheless, these rocks and their significance to the geology at the national monument will be highlighted and explained in the final GRE report and accompanying map unit properties table.

Unique Geologic Resources

Unique geologic resources may include natural features mentioned in a National Park System unit's enabling legislation, features of widespread geologic importance, geologic resources of interest to visitors, and geologic features worthy of interpretation. The GRE Program also considers age dates and type localities as unique geologic features. Falling into this category are the ample geochemical samples and age dates that researchers have taken at Pinnacles National Monument, primarily by investigators from the University of California–Berkeley. In addition the U.S. Geological Survey conducted deuterium-tritium studies of the springs at the national monument. Before this study, the groundwater was assumed to be "young" (≥ 1 year); the results of the study suggest that the groundwater is actually much older (i.e., pre-1952, before nuclear testing) (Borchers and Lyttge 2007).

During scoping Vince Matthews mentioned that he may have proposed a type section at the national monument; the USGS lexicon at http://ngmdb.usgs.gov/Geolex/NewUnits/unit_11593.html confirms this. The type section is exposed along the High Peaks Trail, west of Chalone Peak Campground. This section is depicted on the USGS North Chalone Peak 7.5-minute quadrangle, San Benito County, California, with coordinates from SW/4 SE/4 sec. 35 to SW/4 SE/4 sec. 34 T. 16 S., R. 7 E. Vince Matthews documented the type locality in his PhD thesis (Matthews 1973).

Another "unique geologic resource" mentioned during scoping is the pumice lapilli tuff. The origin of its green color still remains inconclusive despite studies conducted by Peter Weigand and Vince Matthews. Weigand and Matthews presented their work at the Geological Society of America's annual meeting in 2003.

Other Topics

In addition to hiking and exploring caves, rock climbing is a very popular activity at Pinnacles National Monument. Park staff estimates 500 routes containing 3,500 bolts. Hence, the proliferation of social trails, wear-and-tear on staging areas, and amount of rock removed for bolting are a concern for park management. Additionally climbing areas are raptor habitat. The Friends of Pinnacles spreads the word about falcon nesting and encourages members and interested parties to comply with advisories and closures. As its Web site states, Friends of Pinnacles is a "nonprofit organization dedicated to working directly with the National Park Service to preserve rock climbing and the environment at Pinnacles National Monument" (http://www.pinnacles.org/). During scoping, park staff identified that preparing a comprehensive climbing plan is needed.

Potential Research

Scoping participants informally discussed potential research at Pinnacles National Monument as follows:

- Study marine and freshwater ostracodes. Will Elder (Golden Gate National Monument) may be a candidate for carrying out this paleontological investigation.

To refine the geologic story as it relates to the national monument, participants suggested the follow topics:

- Study base rocks to define the start of fault movement.
- Date sedimentary rocks stratigraphically above the rocks exposed at Pinnacles National Monument.
- Map the area around Parkfield, California, for the Pinnacles-Neenach story.

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